TITLE OF THE INVENTION

APPARATUS AND METHOD FOR X-RAY COMPUTED TOMOGRAPHY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the
benefit of priority from prior Japanese Patent
Application No. 2003-091970, filed March 28, 2003,
the entire contents of which are incorporated herein
by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to apparatus and
method for the X-ray computed tomography.

2. Description of the Related Art

The X-ray computed tomographic apparatus (also
referred to as the CT scanner) provides information of
the subject in the form of images on the basis of the
intensity of X-rays having passed through the subject,
and plays an important role in many medical practices
including diagnosis of illness, treatment and operation
planning, etc. The advent of helical scan has made
it possible to achieve wide-range data acquisition in
a short time.

The patient throughput has become one of critical
issues associated with such achievement. Due to
ultrafast scans as well as weight saving of X-ray
tubes, widespread use of helical scan, increasing
number of detector arrays, and enhancement of detection

sensitivity in recent years, the patient throughput is influenced more by a time needed for pre-scan setting of the subject than the scan time. The subject lies on his back on the tabletop of the diagnostic table

5 and fine adjusts the body position according to radiologist's instructions. However, only a limited time is allowed for fine adjustment of the body position. Hence, as is shown in FIG. 1A, scans are often performed while the body axis of the subject is

10 tilted with respect to the center line (Z-axis, the rotational axis of the X-ray tube) of the scan range. This results in an event that, as is shown in FIG. 1B and FIG. 1C, the center of the subject is offset from the center of the image and a degree of offset differs

15 from image to image, which makes observations quite difficult.

BRIEF SUMMARY OF THE INVENTION

An object of the invention is therefore to address an event such that scans are performed while the body

20 axis of the subject is tilted with respect to the center line (Z-axis, the rotational axis of the X-ray tube) of the scan range.

An X-ray computed tomographic apparatus of the invention includes: a display portion to display, on a

25 screen, a scanogram related to a subject together with a quadrilateral frame line specifying a reconstruction range; an input portion to input a command to transform

the frame line specifying the reconstruction range to
a parallelogram or rotate the frame line specifying the
reconstruction range; a gantry to perform scanning in
a scan range corresponding to the reconstruction range;
5   and a reconstruction portion to reconstruct image data
related to plural slices, parallel to one another and
included in the reconstruction range, slice-by-slice on
the basis of projection data acquired by the scanning.

Additional objects and advantages of the invention
10   will be set forth in the description which follows, and
in part will be obvious from the description, or may be
learned by practice of the invention. The objects and
advantages of the invention may be realized and
obtained by means of the instrumentalities and
15   combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated
in and constitute a part of the specification,
illustrate presently preferred embodiments of the
20   invention, and together with the general description
given above and the detailed description of the
preferred embodiments given below, serve to explain
the principles of the invention.

FIG. 1A, FIG. 1B, and FIG. 1C are views used to
25   explain problems in the related art;

FIG. 2 is a view showing the configuration of
an X-ray computed tomographic apparatus according to

an embodiment of the invention;

FIG. 3A and FIG. 3B are perspective views of an X-ray detector of FIG. 2;

FIG. 4 is a view showing helical path of an X-ray tube of FIG. 2;

FIG. 5 is a view showing an example of a scan procedure screen constructed by a scan procedure system of FIG. 2;

FIG. 6 is a view showing a frame line specifying a reconstruction range transformed with a click on a "transformation icon" of FIG. 5;

FIG. 7 is a view showing a frame line specifying a reconstruction range rotated with a click on a "rotation icon" of FIG. 5;

FIG. 8A, FIG. 8B, and FIG. 8C are views used to explain reconstruction processing corresponding to the transformed reconstruction range of FIG. 6;

FIG. 9A, FIG. 9B, and FIG. 9C are views used to explain reconstruction processing corresponding to the rotated reconstruction range of FIG. 7; and

FIG. 10A and FIG. 10B are views showing two types of scan range corresponding to the rotated reconstruction range of FIG. 7.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment of an X-ray computed tomographic apparatus of the invention will now be described with reference to the accompanying drawings. The X-ray

computed tomographic apparatus includes various types,
such as a rotate/rotate type in which a unit comprising
the X-ray tube and the radiation detector rotates about
the subject, and a stationary/rotate type in which

5   a number of detection elements are aligned in a ring-
shaped array and the X-ray tube alone rotates about the
subject, and the invention is applicable to any type.
Herein, the currently most popular rotate/rotate type
will be described. Also, in order to reconstruct

10   tomographic data for one slice, it is necessary to
obtain projection data of about 360° for a full circle
of the subject, and projection data of 180° plus a
view angle is needed even in the half scan method.
The invention is applicable to either reconstruction

15   method. Herein, the former method will be described by
way of example. Also, popular mechanisms to convert
incident X-rays to charges are: an indirect conversion
scheme, by which X-rays are converted first into light
by a fluorescent material, such as a scintillator,

20   and the light is then converted to charges by a
photoelectric converting element, such as a photodiode;
and a direct conversion scheme, by which generation
of electron-hole pairs in the semiconductor by X-rays
and their movement to the electrodes, that is, the

25   photoelectric phenomenon, are exploited. The X-ray
detection elements adopting either scheme can be used,
and herein, those adopting the former indirect

conversion scheme will be described. In addition, a
so-called multi-tube type X-ray computed tomographic
apparatus, in which plural pairs of an X-ray tube and
an X-ray detector are mounted to a rotational ring,
has become commercially available recently, and
the peripheral techniques are also under development.
The invention is applicable to either a conventional
single-tube type X-ray computed tomographic apparatus
or a multi-tube type X-ray computed tomographic
apparatus. Herein, a single-tube type X-ray computed
tomographic apparatus will be described.

FIG. 2 shows the configuration of the X-ray
computed tomographic apparatus according to this
embodiment. The X-ray computed tomographic apparatus
includes a gantry 1 configured to acquire projection
data related to the subject. The gantry 1 includes
an X-ray tube 10 and an X-ray detector 23. Both the
X-ray tube 10 and the X-ray detector 23 are mounted to
a ring-shaped rotational frame 12, which is driven to
rotate about the Z-axis by a gantry driving device 25.
The rotational frame 12 is provided with an aperture
at the center thereof, and the subject P laid on the
tabletop 2a of the diagnostic table 2 is inserted into
the aperture. A slit 22 used to vary the irradiation
width of X-rays depending on the slice thickness is
placed between the X-ray tube 10 and the aperture.

A tube voltage from a high voltage transformer

assembly 21 is applied between the cathode and the anode of the X-ray tube 10, while a filament current from the high voltage transformer assembly 21 is supplied to the filament of the X-ray tube 10. X-rays are generated by the application of the tube voltage and the supply of the filament current.

As is shown in FIG. 3A and FIG. 3B, the X-ray detector 23 includes plural X-ray detection elements 100 each having, for example, a 0.5 mm × 0.5 mm tetragonal light-reception surface. In the case of FIG. 3A, for example, 916 X-ray detection elements 100 are aligned in an array along the channel direction. In the case of FIG. 3B, arrays of FIG. 3A are provided, for example, in 40 rows in parallel along the slice direction. The detector of FIG. 3A is referred to as the single-slice type, and the detector of FIG. 3B is referred to as the multi-slice type. The X-ray detector 23 can be of either type.

A data acquisition device 24, generally referred to as a DAS (data acquisition system), converts a signal in each channel outputted from the detector 23 to a voltage signal, amplifies the voltage signal, and converts the amplified voltage signal to a digital signal. Data (raw data) thus obtained is supplied to a computer unit 3 installed at the outside of the gantry. A pre-processing unit 34 of the computer unit 3 performs compensation processing, such as sensitivity

compensation, on the raw data outputted from the data
acquisition device 24, and outputs projection data.
The projection data is then sent to and stored in
a data storage device 35 of the computer system 3.

5   The computer system 3 comprises a system
controller 29, an input device 39 provided with
a keyboard, a mouse, etc., a display 38, a scan
controller 30, a reconstruction unit 36, and a scan
procedure system 42 in addition to the aforementioned

10   pre-processing unit 34 and the storage device 35. The
reconstruction unit 36 is able to selectively perform
the reconstruction processing according to either of
the followings: the typical fan-beam reconstruction
method (also referred to as the fan-beam convolution

15   back projection method); and a reconstruction method in
a case where projection rays cross with the reconstruc-
tion plane like a cone beam, other than the helical
interpolation that can be used together with the
fan-beam reconstruction method in finding projection

20   data on the reconstruction plane through interpolation
from projection data of, for example, two rotations,
the method including the Feldkamp method, known as
an approximate image reconstruction method, by which
convolution is performed by deeming the beam as a fan

25   projection beam on the assumption that the cone angle
is small and back projection is performed along rays at
the time of scanning, and the cone-beam reconstruction

method, known as a method capable of suppressing cone-angle induced errors compared with the Feldkamp method, by which projection data is compensated in response to the angle of rays with respect to the reconstruction plane.

The scan procedure system 42 is provided to assist the operator in a work of determining the scan procedure, and constructs a scan procedure screen used to set scan conditions, such as a helical pitch (HP) indicating a distance the tabletop moves while the X-ray tube 10 rotates once as shown in FIG. 4, and a scan speed (SS) indicating a time needed for the X-ray tube 10 to rotate once.

FIG. 5 shows an example of the scan procedure screen. The scan procedure screen includes patient information, gantry information, and detailed information of the scan conditions at the bottom of the screen as well as a scanogram image 99. The scanogram image 99 is displayed in an orientation such that the Z-axis (the center of rotation) thereof is parallel to the vertical direction (possibly, the horizontal direction in some cases) of the screen. Thus, when scanogram imaging is performed while the body axis of the subject is tilted with respect to the Z-axis, the scanogram image 99 is displayed on the screen as being tilted with respect to the vertical direction of the screen as well.

The scan conditions include the activation
(distinction between the manual trigger and the
automatic trigger to start the scan), scan start time
(start time), start position of helical scan, a pause

5   between scans, end position of helical scan, scan mode
(distinction among single-slice/multi-slice/helical),
start position of scan, end position of scan, tube
voltage kV, tube current mA, scan speed (time in
parentheses indicates a time needed for the entire

10   scans), the number of slices (the number of arrays
used), helical pitch, reconstruction mode, and FOV
(width of reconstruction range).

A quadrilateral frame line 101 specifying the
reconstruction range is displayed on the scanogram

15   image 99. A frame line, generally in a dotted line,
specifying the scan range corresponding to the
reconstruction range is displayed together with the
frame line 101 specifying the reconstruction range
in some cases. The quadrilateral frame line 101

20   specifying the reconstruction range is initially
provided as an oblong with its center line 109 being
parallel to the Z-axis (central axis of rotation).

Also, rhombic icons 102 for scaling up/down the
range vertically and rhombic icons 103 for scaling

25   up/down the range horizontally are displayed at the
four corners of the frame line 101 specifying the
reconstruction range, so that the operator is able to

scale up/down the reconstruction range as needed by
moving the pointer 104 to any of the icons 102 and 103
and dragging the pointer 104 with the use of, for
example, the mouse of the input device 39. Also, the
operator is able to move the reconstruction range in
parallel vertically and/or horizontally by moving the
pointer 104 on the frame line 101 and dragging the
pointer 104 with the use of, for example, the mouse of
the input device 39.

Further, on the scanogram image 99 are superposed
transformation icons 105 and 106 and rotation icons 107
and 108. A transformation command is inputted with a
click on the transformation icon 105. Upon input of
the transformation command, as is shown in FIG. 6,
the frame line 101 specifying the reconstruction range
is transformed to a parallelogram. A degree of
transformation, that is, a tilt of the center line 109
with respect to the vertical direction of the screen,
is determined, for example, by the number of clicks.
For instance, a tilt of 2.5° is given with one click.
With a click on the other transformation icon 106, the
frame line 101 specifying the reconstruction range is
transformed in an opposite direction to the direction
of FIG. 6. A degree of transformation is also
determined by the number of clicks.

A rotation command is inputted with a click on the
rotation icon 107. Upon input of the rotation command,

as is shown in FIG. 7, the frame line 101 specifying

the reconstruction range is rotated about its center.

A degree of rotation, that is, a tilt of the center

line 109 with respect to the vertical direction of the

5   screen, is determined, for example, by the number of

clicks. For instance, a rotation by 2.5° is given with

one click. With a click on the other rotation icon

108, the frame line 101 specifying the reconstruction

range is rotated in a direction opposite to the

10   direction of FIG. 7. A degree of rotation is also

determined by the number of clicks. Basically,

transformation and rotation are performed

alternatively.

As has been described, the scanogram image 99 is

15   displayed in an orientation such that the Z-axis

(center of rotation) thereof is parallel to the

vertical direction of the screen. Thus, when scanogram

imaging is performed while the subject is tilted with

respect to the Z-axis, the tilt is reflected on the

20   scanogram image 99 on the screen as are shown in FIG. 6

and FIG. 7.

The operator thus drags and moves the frame line

101 specifying the reconstruction range in parallel

and clicks either the transformation icon 105 in the

25   forward direction or the transformation icon 106 in the

backward direction as many times as necessary, so that

the center line 109 of the frame line 101 specifying

the reconstruction range becomes parallel to and agrees
as much as possible with the body axis of the subject
on the tilted scanogram image 99. Also, the operator
drags and moves the frame line 101 specifying the

5   reconstruction range in parallel and clicks either the
rotation icon 107 in the forward direction or the
rotation icon 108 in the backward direction as many
times as necessary, so that the center line 109 of the
frame line 101 specifying the reconstruction range

10   becomes parallel to and agrees as much as possible with
the body axis of the subject assumed on the tilted
scanogram image 99. Alternatively, it may be possible
to transform and rotate the frame line 101 specifying
the reconstruction range with the use of the

15   transformation icon 105 or 106 together with the
rotation icon 107 or 108.

        There is a slight difference between the examples
of FIG. 6 and FIG. 7 in terms of image reconstruction.
When the frame line 101 specifying the reconstruction

20   range is transformed as shown in FIG. 6, the scan
procedure system 42 determines, as is shown in FIG. 8A,
the reconstruction range 111 to correspond to the
frame line 101, and determines the scan range 112 to
correspond to the reconstruction range 111. The scan

25   range 112 is set to the shape of a cylindrical column
whose longitudinal cross section is an oblong having
the Z-axis (axis of rotation) at the center and

covering the reconstruction range 111.

As is shown in FIG. 8B, the reconstruction unit 36 extracts projection data corresponding to respective slices from projection data acquired by scans, and reconstructs image data on the basis of the projection data thus extracted. Widths of the respective slices are set according to the horizontal width of the frame line 101 specifying the reconstruction range, and the centers of the respective slices are set on the center line 109 of the frame line 101 specifying the reconstruction range. Because the center line 109 of the reconstruction range is set with a tilt with respect to the center line of the scan range, the horizontal positions of the respective slices, that is, a distance from the center line of the scan range to the center of each slice, vary from slice to slice. However, the centers of the respective slices are all placed on the body axis of the subject.

Because the center of the slice can be set for each slice in response to the tilted body position of the subject in the manner descried above, even when scans are performed while the body axis of the subject is titled with respect to the Z-axis, the body axis of the subject can be positioned on almost the center of the image as shown in FIG. 8C. This eliminates offset between the position on the image and the position on the subject, which makes observation quite easy.

Also, by converting a horizontal distance of the subject to an actual distance on the basis of the tilt of the frame line 101, it is possible to reduce errors in measurement of a distance or a volume.

5   Then, in a case where the frame line 101 specifying the reconstruction range is rotated as shown in FIG. 7, the scan procedure system 42 determines, as is shown in FIG. 9A, the reconstruction range 111 corresponding to the frame line 101 together with

10   the scan range 112. In this case, the scan range 112 is set to the shape of a cylindrical column whose longitudinal cross section is an oblong having the Z-axis (axis of rotation) at the center and covering the reconstruction range 111.

15   The scan range 112 can be selected from the range shown in FIG. 10A and the range shown in FIG. 10B wider than the one shown in FIG. 10A. In the helical reconstruction, as is known, projection data at the slice position is generated through interpolation

20   from projection data of two, preceding and following rotations. In other words, the helical reconstruction needs projection data that covers a wider range 113, which is wider than the outermost slice within the reconstruction range 111 to the outside by at least one

25   rotation. FIG. 10B shows an example when the scan range 112 is set to acquire the entire projection data of this wider range 113. In contrast, FIG. 10A shows

an example of a narrow scan range 112, in which part of projection data shaded by diagonal lines is replenished through extrapolative interpolation. The operator may make a selection between these two types, or the

5   selection may be made automatically depending on the various conditions of the region to be imaged.

As is shown in FIG. 9B, the reconstruction unit 36 reconstructs image data by either the cone-beam reconstruction method or the tilt reconstruction method

10 for each of plural slices (reconstruction planes) orthogonal to the center line 109 of the reconstruction range rotated in response to a tilt of the body axis of the subject, on the basis of the projection data acquired by scans. In other words, the pixel value of

15 each pixel within the slice tilted with respect to the central axis of the scan range is computed as a filter integral value of projection data of plural X-ray paths that cross with the each pixel diagonally.

The width of each slice is set according to the

20 width of the frame line 101 specifying the reconstruction range, and the center of each slice is set on the center line 109 of the frame line 101 specifying the reconstruction range. Because the center line 109 of the reconstruction range is set with a tilt with

25 respect to the center line of the scan range, the horizontal positions of the respective slices, that is, a distance from the center line of the scan range to

the center of each slice, vary from slice to slice.

Because the center of the slice can be set for

each slice in response to the titled body position of

the subject in the manner described above, even when

5   scans are performed while the body axis of the subject

is tilted with respect to the Z-axis, the body axis of

the subject can be positioned on almost the center of

the image as is shown in FIG. 9C. Moreover, in this

example, an image of a plane orthogonal to the body

10   axis of the subject can be obtained, which reduces

errors in horizontal distance associated with a tilt of

the body axis with respect to the Z-axis. In short, it

is possible to substantially eliminate a state where

the body axis of the subject is tilted with respect

15   to the Z-axis. Because errors in distance can be

eliminated not only vertically but also horizontally,

errors can be reduced in measurement of a distance or

a volume; moreover, MPR (multi-planar reconstruction)

processing or 3-D processing can be performed directly

20   without the need for special compensation processing.

The invention can be applied to, for example, PET

(Positron Emission computed Tomography), as an image

diagnosis apparatus of a type that reconstructs

a planar image on the basis of the subject's data

25   acquired in many directions, as with the X-ray computed

tomographic apparatus.

Additional advantages and modifications will

readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various

5 modifications may be made without departing from the sprit or scope of the general inventive concept as defined by the appended claims and their equivalents.